

HIGH STRENGTH COPPER ALLOY

AND MANUFACTURING METHOD THEREFOR

BACKGROUND OF THE INVENTION

Field of the Invention

This invention relates to high strength copper alloys that contain titanium (Ti) to realize high bend formability and high yield strength. In addition, this invention also relates to manufacturing methods for manufacturing high strength copper alloys.

Description of the Related Art

Conventionally, high strength titanium-contained copper alloy is produced as shown in FIG. 4, in which a prescribed material therefor is subjected to cold rolling and is then subjected to solution treatment upon heating to a temperature ranging from 750°C to 950°C for 1000 seconds and is then subjected to final cold rolling processing; thereafter, it is subjected to precipitation treatment upon heating to a temperature ranging from 300°C to 700°C for a prescribed time ranging from 0.5 hour to 15 hours, for example. This conventional high strength copper alloy contains titanium (Ti) at 2.9-3.5 weight percent, which may be defined by Japanese Industrial Standards Code JISH3130C1990. This alloy can be used for various components and connectors of electronic devices and electric appliances. Due to recent progress of apparatuses and machines in compactness and bend formability, it is necessary for alloy materials to have high bend formability and high yield strength. In order to realize high tensile strength, it may be generally required to improve total reduction rate. As a result, however, an alloy is increased in hardness, causing deterioration of bend formability in manufacture. Bend formability may be improved by reducing total reduction rate by sacrificing tensile strength. The relationship between yield

strength and total reduction rate in final cold rolling is shown by a 'solid' curve in FIG. 3, in which a horizontal axis represents total reduction rate, and a vertical axis represents a ratio between yield strength and tensile strength. The total reduction rate is expressed as follows:

$$\frac{t_1 - t_2}{t_1} \times 100$$

where t_1 denotes a plate thickness of a material after cold rolling, and t_2 denotes a plate thickness of a material after final cold rolling.

As shown in FIG. 3, there is a problem in that when the total reduction rate decreases, the yield strength correspondingly decreases under the constant tensile strength.

SUMMARY OF THE INVENTION

It is an object of the invention to provide a high strength copper alloy having high tensile strength and high yield strength as well as superior bend formability.

It is another object of the invention to provide a manufacturing method for manufacturing the aforementioned high strength copper alloy.

A high strength copper alloy is made of a prescribed material composed of Cu and inevitable impurities as well as titanium (Ti) at 0.1 to 4 weight percent, wherein it is possible to further include at least one of Ag, Ni, Fe, Si, Sn, Mg, Zn, Cr, and P at a prescribed weight percent ranging from 0.01 to 2 in total.

In a manufacturing method, the material is subjected to cold rolling, precipitation treatment, and additional cold rolling sequentially, wherein the reduction rate of the additional cold rolling is set to 3% or more, and the total reduction rate of the cold rolling and the additional cold rolling ranges from 15% to 50%, so that a ratio

of yield strength versus tensile strength is set to 0.9 or more.

In addition, it is possible to perform stress relaxation annealing after the additional cold rolling, wherein the material is heated to a temperature ranging from 200°C to 700°C for a prescribed time ranging from 0.5 hour to 15 hours, or it is heated to a temperature ranging from 300°C to 950°C for a prescribed time ranging from 10 seconds to 1000 seconds.

BRIEF DESCRIPTION OF THE DRAWINGS

These and other objects, aspects, and embodiments of the present invention will be described in more detail with reference to the following drawings, in which:

FIG. 1 is a brief diagram showing a manufacturing process of a high strength copper alloy in accordance with a first embodiment of the invention;

FIG. 2 is a brief diagram showing a manufacturing process of a high strength copper alloy in accordance with a second embodiment of the invention;

FIG. 3 is a graph showing curves representing ratios of yield strength versus tensile strength in copper alloys produced in the present invention compared with a conventional art;

FIG. 4 shows a manufacturing process for a conventional high strength copper alloy;

FIG. 5 is a table showing processing conditions of samples compared with comparative samples; and

FIG. 6 is a table showing characteristics of samples compared with comparative samples.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

This invention will be described in further detail by way of examples with reference to the accompanying drawings.

FIG. 1 shows a manufacturing process for a high strength copper alloy in accordance with a first embodiment of the present invention. Herein, a copper alloy material containing titanium (Ti) at 1 to 4 weight percent is subjected to cold rolling and is then subjected to solution treatment upon heating to a temperature ranging from 750°C to 950°C for a prescribed time ranging from 10 seconds to 1000 seconds. Prior to precipitation, cold rolling is performed on the material; thereafter, precipitation treatment is performed at a temperature ranging from 300°C to 700°C for a prescribed time ranging from 0.5 hour to 15 hours. Thereafter, additional cold rolling is performed on the material. Incidentally, the aforementioned material is prepared by way of a vacuum melting furnace introducing pure copper (Cu) and pure titanium (Ti) and is then cast into an ingot having prescribed dimensions such as 50 mm thickness and 150 mm width, for example.

In the first embodiment, the reduction rate of the additional cold rolling is set to 3% or more, so that the total reduction rate may range from 15% to 50%. Thus, it is possible to express an additional cold rolling reduction rate in accordance with an equation 1, in which reference symbol t₁ denotes a plate thickness of a material produced by the cold rolling, t₂ denotes a plate thickness of a material produced by the cold rolling before precipitation, and t₃ denotes a plate thickness of a material produced by the additional cold rolling, as follows:

$$\text{Additional cold rolling reduction rate} = \frac{t_2 - t_3}{t_2} \times 100$$

In addition, the total reduction rate may be defined as the total reduction rate counting the cold rolling before precipitation and the additional cold rolling; therefore,

it can be expressed in an equation 2 as follows:

$$\text{Total reduction rate} = \frac{t_1 - t_3}{t_1} \times 100$$

The reasons why the additional cold rolling reduction rate is set to 3% or more will be described below.

That is, if the additional cold rolling reduction rate is less than 3%, it is necessary to increase the total reduction rate in order to realize a high strength for a copper alloy, which, however, results in deterioration of bend formability. Since the reduction rate of the conventional art is substantially set to 0%, the present embodiment becomes close to the conventional art in property if the reduction rate is less than 3%, wherein in order to produce yield strength matching 90% or more of the tensile strength, it is necessary to increase the total reduction rate to be 50% or more, whereas if the total reduction rate exceeds 50%, a hardening process may be caused to occur intensely in cold rolling so that a copper alloy product must be deteriorated in bend formability. Thus, it is preferable for the present embodiment to set the additional cold rolling reduction rate to be 3% or more.

The reasons why the total reduction rate is set in a range from 15% to 50% will be described below.

That is, if the total reduction rate is less than 15%, yield strength becomes less than 90% of the tensile strength; in other words, yield strength must be greatly decreased. In contrast, if the total reduction rate exceeds 50%, a hardening process may be caused to occur intensely in cold rolling so that a copper alloy product must be deteriorated in bend formability. Thus, it is preferable for the present embodiment to set the total reduction rate in a range from 15% to 50%.

The present embodiment is characterized in that the precipitation treatment is

followed by the additional cold rolling; in other words, the precipitation treatment is performed before the final cold rolling (i.e., additional cold rolling). Thus, it is possible to actualize a high yield strength in a copper alloy product upon a reduced value of cold rolling reduction rate (or total reduction rate).

A dotted curve shown in FIG. 3 represents the property of a high strength copper alloy. Compared with the solid curve representing the property of the conventional copper alloy, a value of yield strength against the tensile strength is increased to be higher and is therefore improved in the copper alloy of the present embodiment at the same total reduction rate. FIG. 3 noticeably shows that the present embodiment can offer a sufficient high value of yield strength matching 90% of the tensile strength at a lower-limit value of 15% of the total reduction rate.

As shown in FIG. 4, a Cu-Ti alloy is produced through precipitation treatment that is performed generally at a relatively high temperature, which results in a high heat resistance. The present embodiment is characterized in that the additional cold rolling is performed after the precipitation process, which may present a possibility that the heat resistance will be reduced. Actually, however, the copper alloy of the present embodiment can demonstrate substantially the same heat resistance compared with the conventional copper alloy. This is because dislocation due to the additional cold rolling after the precipitation process may be subjected to pinning by precipitates and be avoided.

As described above, the present embodiment can increase the yield strength to match 90% or more of the tensile strength even when the total reduction rate is 50% or less. When the copper alloy of the present embodiment is compared with the conventional copper alloy at the same total reduction rate, it is possible to actualize the following advantages:

- (i) It is possible to increase both the tensile strength and yield strength.
- (ii) It is possible to actualize the bend formability to match that of the conventional copper alloy or higher.
- (iii) It is possible to bend the material at a relatively small bending radius.

In the conventional copper alloy (see the solid curve in FIG. 3), it is necessary to increase the total reduction rate to be 50% or more in order to realize a sufficiently high yield strength substantially matching 90% or more of the tensile strength. That is, it is necessary to perform cold rolling with a relatively large scale or power, which noticeably deteriorates bend formability. In contrast, the present embodiment can offer a ratio of yield strength versus tensile strength at 0.9 even when the total reduction rate is set to 15%.

Next, a second embodiment of the present invention will be described with reference to FIG. 2. Similar to the first embodiment shown in FIG. 1, the second embodiment shown in FIG. 2 performs cold rolling, solution treatment, cold rolling before precipitation, precipitation treatment, and additional cold rolling in turn. The second embodiment is characterized by performing stress relaxation annealing after the additional cold rolling, wherein an alloy coil is put into a batch type furnace in which it is heated to a temperature ranging from 200°C to 700°C for a prescribed time ranging from 0.5 hour to 15 hours; preferably, it is heated to a temperature of 350°C for three hours, for example. Alternatively, an alloy coil is put into a continuous furnace in which it is heated to a temperature ranging from 300°C to 950°C for 10 seconds to 1000 seconds; preferably, it is heated to a temperature of 500°C for 30 seconds, for example.

Since the second embodiment performs stress relaxation annealing after the additional cold rolling under the aforementioned conditions, it is possible to improve

spring characteristics (e.g., spring limit values), which have been slightly reduced in the additional cold rolling. Therefore, it is possible to obtain relatively high spring limit values while securing relatively high bend formability and relatively high yield strength.

The aforementioned stress relaxation annealing is performed for the purpose of improvements of spring characteristics without deteriorating the material in strength, conductivity, and bend formability. Specifically, the batch type furnace or continuous furnace is used to perform the stress relaxation annealing. In the batch type furnace, heating is performed at a temperature ranging from 200°C to 700°C for 0.5 hour to 15 hours. This is because it is difficult to improve spring characteristics, which have been reduced in the additional cold rolling, at a relatively low temperature less than 200°C, and yield strength must be reduced due to progress of recrystallization at a relatively high temperature higher than 700°C. In addition, it is difficult to expect uniform annealing progressed in the batch type furnace when annealing is performed only for 0.5 hour. Furthermore, aging must be progressed too rapidly to realize improvement of spring characteristics so that bend formability must be deteriorated when annealing is performed for 15 hours or more.

In the continuous furnace, heating is performed at a temperature ranging from 300°C to 900°C for 10 seconds to 1000 seconds. This is because when the heating temperature is less than 300°C, heating must be performed for a long time, resulting in a reduction of productivity, wherein it is difficult to improve spring characteristics, which have been reduced in the additional cold rolling, when heating temperature is very low. In addition, when heating temperature is higher than 900°C, solution treatment is progressed so rapidly that yield strength and conductivity are reduced. Furthermore, when heating is performed for a short time less than 10 seconds, the

material cannot be sufficiently heated so that spring characteristics cannot be improved. When heating is performed for a long time greater than 1000 seconds, productivity must be reduced.

The copper alloy has a prescribed composition including titanium (Ti) at 0.1 to 4 weight percent. If the titanium content is appropriately set, it may be possible to produce a copper alloy having a high strength because the titanium content is increased so that an amount of precipitation hardening must be increased during manufacturing processes. However, conductivity and bend formability must be reduced, so that productivity must be correspondingly reduced. That is, when the titanium content is less than 0.1 weight percent, a copper alloy must be decreased in strength because of a relatively small amount of precipitation hardening. When it exceeds 4 weight percent, a copper alloy must be deteriorated in characteristics so that productivity must be decreased. Because of the aforementioned reasons, the titanium content is set in a range from 0.1 to 4 weight percent.

In the second embodiment, it is possible to selectively use at least one of Ag, Ni, Fe, Si, Sn, Mg, Zn, Cr, and P, which can be contained in the material at a ratio ranging from 0.01 to 2 weight percent in total. These elements may present an improvement of the strength of Cu-Ti alloy due to precipitation hardening and solid solution hardening. When the total of these elements is less than 0.01 weight percent, it is very difficult to obtain the aforementioned effect. When it exceeds 2 weight percent, these elements must deteriorate reduction rate in production of Cu-Ti alloy, which may result in reduction of conductivity and bend formability.

Next, characteristics of the embodiments will be described in detail upon comparison between samples (corresponding to the embodiments) and comparative samples that do not match the embodiments in compositions and processing

conditions.

As a material, pure Cu and pure Ti are adequately blended together and are then introduced into a vacuum melting furnace, thus producing an ingot having prescribed dimensions such as 50 mm thickness and 150 mm width. The material is heated up to 900°C and subjected to homogenization; then, the material is subjected to solution treatment upon heating to a temperature of 900°C for 70 to 200 seconds. Then, cold rolling before precipitation is performed under prescribed conditions, which are shown in FIG. 5. Then, the material is subjected to precipitation treatment upon heating at a temperature of 450°C for 6 hours; thereafter, the additional cold rolling after precipitation is performed under prescribed conditions shown in FIG. 5. Thus, it is possible to produce samples 1-11 (corresponding to the embodiments), each of them is subjected to additional cold rolling to realize a plate thickness of 0.30 mm after final cold rolling. In addition, comparative samples 12-22 are also produced without performing additional cold rolling, wherein each of them is subjected to cold rolling before precipitation to realize a plate thickness of 0.30 mm after final cold rolling. In the above, samples 8-11 (corresponding to the embodiments) and comparative samples 19-20 are subjected to stress relaxation annealing after additional cold rolling.

Characteristics of copper alloys that are produced as samples 1-11 and comparative samples 12-22 are shown in FIG. 6, wherein assessments using Japanese Industrial Standards (JIS) are performed with respect to tensile strength according to JIS-Z2241, yield strength according to JIS-Z2241 (allowing 0.2% offset in yield strength), elongation according to JIS-Z2241 (breaking elongation), conductivity according to JIS-H0505, spring characteristics according to JIS-H3130 (spring limit values), bend formability according to JIS-H3130 (W bending), and heat resistance

according to stress relaxation characteristics, for example. Incidentally, the bend formability is assessed through the observation of the exterior of a bent portion upon estimation of a minimum bent radius causing no crack at a prescribed total reduction rate, as follows:

- (i) If no crack occurs even when a sample is bent at a certain radius, identical to that of the conventional alloy or less, the assessment result is "fine" (denoted by 'O' in FIG. 6) in bend formability.
- (ii) If cracks occur when a sample is bent at a greater radius, the assessment result is "not good" (denoted by 'X' in FIG. 6) in bend formability.

In addition, the stress relaxation characteristics are assessed under prescribed conditions in which each sample is formed in 10 mm width and L mm length, and is wound about an instrument having a radius r , to which a certain stress is applied and which is heated to 230°C for 1000 hours; thus, a degree of stress relaxation is expressed in percent.

FIG. 6 shows that each of samples 1-4 and 7-11 is superior in both tensile strength and yield strength in comparison with comparative samples at the same total reduction rate, wherein a ratio of yield strength versus tensile strength is 0.9 or more. In addition, each of them is also superior in bend formability, which is equal or high than that of the comparative sample. Furthermore, each of them is superior in heat resistance as well. Each of samples 5-6 may be somewhat weak in tensile strength and yield strength because of a reduction of titanium content, wherein similar to the aforementioned samples, each of them has a relatively high ratio of yield strength versus tensile strength, which is 0.9 or more. As shown in FIG. 5, each of samples 8-11 is subjected to stress relaxation annealing; therefore, each of them is superior in spring limit value in comparison with the foregoing samples 1-7 while securing high

yield strength and high bend formability.

Comparative sample 12 has a relatively low ratio of yield strength versus tensile strength, which is 0.88, because of a relatively low additional cold rolling reduction rate that is 2% (see FIG. 5). Comparative example 13 offers relatively low elongation and relatively low conductivity because of a relatively high total reduction rate that is 70%.

Each of comparative samples 14-18 substantially corresponds to the conventional alloy that is produced without performing additional cold rolling, wherein each of them is reduced in a ratio of yield strength versus tensile strength, and it offers very small elongation.

Comparative sample 19 cannot demonstrate improvement in spring characteristics because of a relatively low temperature in stress relaxation annealing. In contrast, comparative sample 20 not only has improved spring characteristics but also degraded bend formability due to progress of aging because of the relatively long time in stress relaxation annealing.

Comparative sample 21 is reduced in strength because of a relatively small titanium content and is also reduced in heat resistance. Comparative sample 22 is reduced in both tensile strength and yield strength because of a relatively high titanium content and is remarkably reduced in bend formability.

As described heretofore, this invention have a variety of effects and technical features, which will be described below.

(1) It is possible to produce a copper alloy that is increased in tensile strength and yield strength, wherein it is possible to increase a ratio of yield strength versus tensile strength. That is, it is possible to produce a high strength copper alloy having superior bend formability, which is also improved in spring characteristics due to

stress relaxation annealing.

- (2) Specifically, a high strength copper alloy of this invention contains titanium (Ti) at 0.4 to 4 weight percent, wherein it is basically composed of copper (Cu) and inevitable impurities. That is, a prescribed material is subjected to cold rolling and precipitation treatment, and is then subjected to additional cold rolling. Herein, the reduction rate of the additional cold rolling is set to 3% or more, and the total reduction rate for the cold rolling and additional cold rolling is set in a range from 15% to 50%, for example. Thus, it is possible to realize a relatively high ratio of yield strength versus tensile strength, which is 0.9 or more.
- (3) In addition, at least one of Ag, Ni, Fe, Si, Sn, Mg, Zn, Cr, and P can be selectively introduced into a high strength copper alloy at a prescribed weight percent ranging from 0.01 % to 2 %, for example.
- (4) After the additional cold rolling, the material can be subjected to stress relaxation annealing in which it is heated to a temperature ranging from 200°C to 700°C for 0.5 hour to 15 hours, or it is heated to a temperature ranging from 300°C to 950°C for a prescribed time ranging from 10 seconds to 1000 seconds, for example.

As this invention may be embodied in several forms without departing from the spirit or essential characteristics thereof, the present embodiments are therefore illustrative and not restrictive, since the scope of the invention is defined by the appended claims rather than by the description preceding them, and all changes that fall within metes and bounds of the claims, or equivalents of such metes and bounds are therefore intended to be embraced by the claims.